

important cortical regions. The most commonly mapped functions include motor and sensory (simple functions) and language and memory (higher cortical functions).

Preoperative studies are done to help predict functional anatomy. Neuropsychometric studies can predict hemispheric dominance and document subtle preexisting cognitive deficits in areas such as verbal and visuospatial memory. The Wada test (intracarotid amobarbital administration during cerebral angiography) transiently disrupts function in one hemisphere, allowing the confirmation of hemispheric dominance. Newer modalities such as magnetic source imaging and functional magnetic resonance imaging promise to augment the armamentarium of non-invasive mapping, but have yet to replace conventional computed tomography or magnetic resonance imaging as standard preoperative studies.

During the surgical procedure, electrical stimulation mapping identifies functional cortex. When an electrical current is applied to the surface of the brain, a reversible localized depolarization elicits or blocks the function of that portion of the brain until the current is removed. Motor movements can be seen, sensory phenomena can be reported, and language can be interrupted during language tasks. Craniotomies while patients are awake are possible because the brain does not feel pain or touch. With a regional local anesthetic block and propofol, an ultrashort-acting intravenous anesthetic agent, patients are put to sleep for the opening without requiring intubation, awakened for the functional mapping, and put back to sleep for the remainder of the operation and the closure. Once awake, low currents and 60-Hz biphasic square wave pulses of 1-millisecond duration are used to map the motor and sensory cortices of the face and hand. In dominant-hemisphere operations, the patient is asked to count aloud, and stimulation mapping then identifies counting arrest sites. These sites are usually associated with face motor function. Language sites are mapped by applying the current to the brain surface while the patient names slides of simple objects every four to five seconds. Other modalities such as vision, the ability to read music, to generate verbs from nouns, to speak a second language, to perform sign language, and to do mathematical calculations can also be mapped if necessary. Once important functions are identified, the operation continues with the avoidance of functional areas. With these techniques, permanent neurologic morbidity from tumor resection operations can be kept below 5%.

Brain mapping techniques increase the safety of brain tumor operations and allow for tumor resection with less risk of postoperative deficit.

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Percutaneous Discectomy—Update

PERCUTANEOUS TECHNIQUES for treating radiculopathy due to herniated lumbar discs have stimulated keen interest. This interest is prompted by a need for less invasive techniques, experience with percutaneous approaches in other surgical specialties, and rapidly advancing technology.

The first procedures for percutaneous discectomy used fluoroscopically guided manual instruments that were designed to remove nucleus pulposus (nucleotomy) and possibly contiguous herniated fragments through an intradiscal approach. An automated disc aspirator and laser have recently been used to remove larger amounts of nuclear material in a shorter time. These procedures are purported to decrease irritation of the nerve root and other innervated structures by either eliminating inflammatory mediators (disc material) or reducing intradiscal pressure. Automated disc extraction has recently been found to remove minimal amounts of disc in a sheep model, leading investigators to hypothesize that perforation of the annulus alone may be responsible for the observed clinical results. Reported outcomes for both manual and automated nucleotomy range from 44% to 85%, with results lasting as long as two years, compared with 75% to 90% with routine microdiscectomy. Complications have been rare, but include infection, hemorrhage, damage to the lumbar nerve roots, penetration of instruments into the thecal sac, and injury to the cauda equina.

Newer technologies are making simple nucleotomy obsolete as surgeons now can remove disc fragments that are impinging on nerve roots and percutaneously fuse degenerated disc spaces. Stereotactic localization of intradiscal targets and disc fragments to avoid entry into the thecal sac or damage to extraspinal nerve roots and vessels is being investigated. Stereotactic localization may eventually be used to guide instruments directly to an offending disc fragment within the neural foramina, allowing its removal.

With an intradiscal approach, angled instruments and aspiration probes guided by both rigid and flexible endoscopes are being used in an attempt to remove the nuclear material in disc bulges and to snare free fragments. This technology is also being used to remove fragments through foraminal approaches because the endoscope allows the exiting nerve root, vessels, and herniated fragments in the foramina to be easily identified. With these technologies, the concept of removing large amounts of nucleus and concomitantly reducing intradiscal pressure may be moot as the offending herniation is able to be removed.

Along with newer instruments, various multiportal approaches are being attempted with endoscopes and specialized tools to better remove nuclear material and view and remove fragments accurately from an intradiscal approach. Disc spaces are also being fused using these approaches and a transabdominal approach. Whether these approaches are superior to a single-tract approach has yet to be determined.

The growing excitement for percutaneous techniques should be tempered by an honest assessment of the

success of these techniques. Although many articles have reported substantial short-term clinical improvement following a variety of different percutaneous techniques, a multicenter, prospective, randomized study comparing percutaneous discectomy with open lumbar microdiscectomy has not been done. The National Institutes of Health has recently funded such a study, to be undertaken at several centers throughout the United States. The results of this study will provide a base on which to assess further advances in percutaneous technology.

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Tethered Cord Syndrome

THE TETHERED CORD SYNDROME is an increasingly recognized clinical disorder usually associated with spinal defects such as myelomeningocele, diastematomyelia, lipomyelomeningocele, thickened filum terminale, and intradural lipoma. Tumors such as epidermoids or dermoids, arachnoiditis, and iatrogenic retethering from suturing can also be responsible for the syndrome.

A diagnosis of tethered spinal cord is made when symptoms occur because the conus medullaris is below the level of L-2. The pathophysiology, which has been delineated by many investigators, is that the spinal cord is subject to injury from mechanical, vascular, and metabolic forces when it is placed under tension from the aforementioned lesions.

The clinical picture can be dramatic or insidious. Both motor and sensory loss develop, or patients have a change in their bladder or bowel function. Young children will have skeletal growth deformities such as a leg-length discrepancy or scoliosis. Adolescent or young adult patients often complain of long-term back pain. Physical examination findings can be unimpressive or include a combination of lower and upper motoneuron abnormalities. Good clues to the presence of a tethered spinal cord are cutaneous signs associated with occult spinal dysraphism, such as an abnormal hair pattern in the lumbosacral area ("fawn tail"), fatty masses associated with lipomyelomeningocele or perhaps deep dimples or sinus tracts, or small angiomaticus-appearing birthmarks in the midlumbar areas. Of course, the skeletal deformities can be found on examination.

Evaluation of such findings should include magnetic resonance imaging (MRI) of the lumbosacral spine. This standard imaging study will detect the presence of a tethered spinal cord and almost always will delineate the cause. Exceptions might be in cases of thickened filum

terminale, which can be difficult to ascertain even on a high-quality MRI. In infants, a high-resolution ultrasound examination can often be a good screening test because the conus can be shown nicely and many of the lesions detected.

A patient's lower urinary tract should also be evaluated. Urodynamic studies are sensitive indicators of lower tract compromise. When available, this would be the preferred examination. Follow-up urodynamic studies will often be the first indicator of retethering effects, perhaps before the patient is aware of any changes in function and certainly before any changes in the neurologic system can be found.

Most American pediatric neurosurgeons recommend that patients with the tethered cord syndrome have exploration and release of the spinal cord at the time of diagnosis. This position is controversial and is not completely embraced by the European medical community. Nevertheless, there is good evidence that a preemptive release of a tethered spinal cord to prevent the occurrence of neurologic and urologic deficits is in a patient's best interest. Often function is not completely restored if the operation is done after a deficit has already occurred.

Operative techniques and requirements for special instrumentation vary depending on the specific disorder and a surgeon's experience. Lipomyelomeningoceles and diastematomyelias often present great challenges. Many find the operative microscope especially useful for visualization and minimal manipulation of neural tissue. A spacious dural closure is more important than a total resection of the intradural fatty elements in lipomyelomeningoceles. Procedures to remove dermal sinus tracts are the easiest, as the tract can be kept intact and followed through the fascial defect to its termination at the dura or beyond.

The issue of retethering after the initial operation has generated a great amount of attention. Various suggestions and techniques for minimizing the incidence of retethering have been put forth, but none have proved to be completely effective or superior. They range from simplistic maneuvering, such as placing gel film over the neural elements before dural closure, to the use of plastic and silastic interposition materials, to actually reconstituting the posterior neural arches with bone grafts.

A frequent concern is patients with myelomeningocele in whom spasticity has developed in the lower extremities or neurologic function is being lost. These patients represent the most difficult management issues because they have a high propensity to retether. At the initial repair of myelomeningoceles, a suture of the neural placode with fine, absorbable suture material to reconstitute a neural tube has been advocated to minimize the retethering possibilities.

Surgical management, although challenging, is usually rewarding. Patients with a painful tethered cord syndrome almost invariably have relief of pain following the procedure. Often patients who have incontinence become continent, and many of the children with